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Analysis

Phasing Out Mercury? Ecological Economics and Indonesia's Small-Scale Gold Mining Sector

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ABSTRACT

This article uses an ecological economics approach to analyse tensions surrounding efforts to phase out mercury in Indonesia's artisanal and small-scale gold mining (ASGM) sector, among the largest sources of mercury pollution worldwide. Many scholars and environmental activists have long hoped that global restrictions in mercury trade would drive up mercury prices and decrease mercury use and pollution in ASGM. However, in Indonesia, despite global mercury trade restrictions, recent increases in domestic mercury supplies through new cinnabar mining developments have made mercury less expensive and more available, destabilizing efforts at reducing mercury use. This article discusses implications of domestic cinnabar mining for controlling mercury in Indonesia's ASGM sector, highlighting obstacles to implementing the Minamata Convention, a treaty that aims to restrict mercury use. We link discussion of mercury mining to other socioeconomic processes, labour relations and power dynamics shaping mercury use in gold mining and hindering collectivised mercury-free technology uptake. Examining new evidence regarding the social metabolism of a changing extractive economy, we underscore why an integrated ecological economics paradigm – carefully grounding analysis in the context of local labour situations – is needed to challenge assumptions and inform new strategies for mercury reduction/elimination in ASGM.

1. Introduction

Over the past decade, scholars addressing mercury pollution have drawn attention to the proliferation of contaminated sites in artisanal and small-scale gold mining (ASGM) areas globally, employing a variety of approaches to studying the social and ecological costs of pollution (Li et al., 2009; Bose-O'Reilly et al., 2010; Telmer and Veiga, 2009). There has also been a significant body of literature on technologies for reducing mercury use in gold extraction (García et al., 2015; Appel and Na-Oy, 2012) as well as socioeconomic influences on gold mining practices (Spiegel, 2009; Spiegel, 2012a; Hilson, 2006; Dondeyne and Ndunguru, 2014; Saldarriaga-Isaza et al., 2013). However, there has been a paucity of literature, particularly in Asia, focusing on relationships between mercury production, trade flows, mercury use in ASGM and the inter-connectedness of different extractive processes along gold/mercury commodity chains and their associated labour and power dynamics. In this paper, we focus on challenges in reducing mercury pollution in Indonesia's ASGM sector. After years of inter-governmental debates culminating in the Minamata Convention on Mercury (UNEP, 2013a), the Government of Indonesia announced its plan to phase out mercury use in ASGM completely by 2018. Signed by Indonesia and more than 120 other countries, the Minamata Convention stipulates that countries with "more than insignificant" ASGM activity develop National Action Plans for this sector, including measures to control mercury trade, capacity-building to raise risk-awareness and support cleaner technology adoption in ASGM communities, formalization or regulation of ASGM, and other measures that emerged after years of extensive inter-governmental negotiation (Fritz et al., 2016; Selin, 2014a; Selin, 2014b; Clifford, 2014; Spiegel et al., 2015; Sippl, 2015). We explore the ecological economics of mercury phase-out for the ASGM sector, highlighting a need to rethink assumptions underlying past market- and technology-centred solutions and carefully link analysis of mercury trade dynamics, institutional regulatory strategies and regional socioeconomic processes that shape on-going mercury use in gold mining areas.

Bringing attention to ecological implications of global trade,

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researchers and environmentalists have long argued that curtailing the international trade of mercury should have the effect of increasing mercury prices and reducing mercury use in all sectors, especially gold mining (Hylander, 2001). However, notwithstanding the ethical importance of international mercury trade restrictions, there have also been cautionary warnings that strict mercury trade bans could have the unintended effect of leading to new illegal mercury stockpiling and illegal dealing, thus accentuating the need for new attention to these "unofficial" dynamics – and the socioeconomic relationships in which they are embedded (Spiegel et al., 2005; Clifford, 2014). As Greer et al. (2006) noted, "It is crucially important that any mercury reduction strategy ratchet down supply and demand in a coordinated manner. This will ensure that steps taken to reduce demand do not flood the market with excess mercury supplies, which would invite mismanagement. Similarly it will ensure that a plummet in supply does not trigger a re-opening of already closed primary mines to meet unsatisfied demand" (p. 108). In this article we provide analysis of how, despite mercury export bans by previously significant global mercury suppliers – namely the U.S. and the European Union – and global commitments to phase out mercury use, increases in domestic mercury supplies through new cinnabar mining (HgS) developments in Indonesia have made mercury less expensive and more available to small-scale gold miners across the country, destabilizing efforts at reducing mercury use and pollution. Discussing implications of recent domestic cinnabar mining for mercury use in Indonesia's ASGM sector, we stress the need for an ecological economics perspective that positions the implications of new mercury mining within Indonesia as part of a broader set of concerns about material flows, labour and power relations, and the social metabolism that underpins extractive economy developments (Martinez-Alier et al., 2010; Muradian et al., 2012). We also highlight key insights acquired from engaged research in small-scale mining communities during projects aiming to build capacities to reduce mercury use, agreeing with Muradian and Cardenas (2015) about the need to critically re-conceptualise environmental governance challenges not as "technical" problems but as "collective action dilemmas" that are nested in, and influenced by, broader social processes and value systems.

In understanding social and ecological processes in the extractive sector, Martinez-Alier and Walter (2016) articulate the importance of understanding links between unequal property rights, inequalities of power, pollution burdens and how access to natural resources are unequally distributed. We examine some of these links in areas of Indonesia where mining activities are booming, thus offering a country-specific analysis of key challenges and processes hindering the implementation of Article 7 of the Minamata Convention, which mandates that signatories "shall take steps to reduce, and where feasible eliminate, the use of mercury and mercury compounds in, and the releases to the environment of mercury from, such [gold] mining and processing" (Article 7, Paragraph 2). The first section below provides background of mercury use in Indonesia's ASGM sector, contextualizing how Indonesia's signing of the Minamata Convention represents a moment for invigorating focus on inequities in the gold mining sector. The next section discusses our methodology and analytical approach. This is followed by analysis of recent increases in domestic mercury mining and trade, and its implications for the economics of mercury use in ASGM across Indonesia. The final section builds on papers in *Ecological Economics* by Saldarriaga-Isaza et al. (2015a, 2015b) to highlight a need for strategies of mercury phase-out that closely engage socioeconomic and labour relations surrounding "cheap mercury" and "free mercury" as well as critical lessons learned from past efforts to support co-operatives as a means of replacing mercury use in ASGM with alternative technologies. In particular, our field experiences in Java and Kalimantan reinforce the concern that "rendering society technical" (Li, 2011) perilously neglects complex economic and power dynamics surrounding unequal access to ASGM legalisation opportunities – dynamics that inhibit local groups from transforming extraction technology. We call for careful understanding of inter-linked socioeconomic relations and power dynamics that shape technology choices, material flows and mercury use practices.

2. Contextualizing the Ecological Economics of ASGM and Mercury in Indonesia

Globally, much environmental scholarship has stressed that ASGM is one of the world's largest sources of mercury emissions and that new interventions are urgently needed in this sector (Veiga et al., 2014a; Davies, 2014; Swain et al., 2007; Sippl and Selin, 2012). Indonesia is recognized by the United Nations as the world's third largest mercury emitter after China and India, with reports warning that mercury use and pollution in Indonesia's ASGM sector has been increasing significantly over the past two decades (IPEN, 2015; Balifokus, 2015; Spiegel and Veiga, 2006). Addressing the period immediately before Indonesia signed the Minamata Convention on Mercury, Ismawati (2014) examined how US$32 million in mercury was exported to Indonesia in 2012, largely for use in ASGM, noting a long-term correlation between the upward global gold prices and increased mercury imports into Indonesia between 1998 and 2012. The selection of 2018 for a complete mercury phase-out was the Indonesian Government's own target, not a globally "required" target, and speaks to the urgency with which some government authorities have approached pollution in ASGM in policy announcements. Yet, while its ambitious pollution phase-out target has been welcomed by some, government announcements regarding Indonesia's mercury plans have already elicited a range of sceptical responses. As one prominent Indonesian environmentalist noted, "Indonesia is the first to publish its national action plan…But it was made in a rush and did not involve other stakeholders" (quoted in Mongabay, 2015), highlighting a problem of not investing enough time and resources into vital participatory processes. Critiques have been levied by environmental activists that Indonesia's National Action Plan is not compliant with the Minamata Convention and does not follow Annex C guidelines; and concerns about minimal participation have also been voiced by Indonesia's National Association of Community Miners, which has argued that the government's failure to legalise ASGM is the single greatest challenge that obstructs plans for significant mercury reduction, leaving technology planning to occur in a largely informal context that lacks regulatory support (Lestaripost, 2015). Further concerns have been raised that Indonesia is currently importing significant quantities of mercury "under the table" and "backed by powerful officials" (Ismawati, 2014), creating trade relations that could be difficult to police even if Indonesia's government authorities wanted to reduce mercury importing officially.

Across Indonesia, artisanal and small-scale gold mining activities provide livelihoods to more than one million people, spanning 27 provinces (Balifokus, 2015). In broad technical terms, there are two types of ASGM - hard rock gold mining (primary ore) and alluvial gold mining (secondary ore) - each involving a range of ore types (and grades), technologies, mercury management practices and socio-economic dynamics. Mercury is more heavily used in hard rock gold mining than in alluvial gold mining, although both types of ASGM can result in significant mercury pollution and toxic exposure (Bose-O'Reilly et al., 2010; UNEP, 2013b). National news media coverage in Indonesia has widely stressed that ASGM "costs the nation millions" (Nainggolan, 2015), highlighting ecological and health consequences of toxic contamination. Yet, much like in other countries where mercury has been thought of as an "agent of poverty" in the ASGM sector (Hilson and Pardie, 2006), studies have shown that alternative (mercury-free) technologies (e.g. direct cyanidation) usually require a higher order of economic capital investment and technical training as well as different labour and revenue-sharing relationships, while mercury amalgamation is generally the quickest, least expensive and easiest to manage gold recovery method for individual miners (Veiga et al., 2014a; Spiegel and Veiga, 2010).

The notion of mercury as an "agent of poverty" can have varying situated meanings depending on the context. Financial and technology dynamics of the ASGM sector are embedded in complex social, economic and political relationships. In some cases, "poverty" is linked to inequities associated with gold processing activities driven by powerful actors who can (depending on the situation) make or influence key technological choices and extraction practices, including wealthy businessmen (from the mining regions or from other cities) who may serve as land owners and equipment owners as well as gold shop owners and police (Agrawal, 2007; Spiegel, 2012b; Peluso, 2016). Mercury is also an "agent of poverty" in the sense that its use can be dependent on injustices linked to social marginalisation and territorial conflict; past studies addressing other country contexts suggest that mercury pollution risks can increase when small-scale gold miners have no secure, formally recognized access to resource rights and are treated indiscriminately as "criminals" by companies and government agents (Tschakert and Singha, 2007; Spiegel et al., 2015).[1]

Regardless of which social actors drive technology choices and how these relations may be understood, the Minamata Convention requires signatory governments to establish actions to eradicate the four most hazardous practices of mercury usage in ASGM: whole ore amalgamation, open burning of amalgam or processed amalgam; burning of amalgam in residential areas; and cyanide leaching of ore or tailings to which mercury has been added (UNEP, 2013a). While the Indonesian Government's publicly articulated commitment is to eliminate *all* mercury use in ASGM by 2018, other countries have recently announced plans to adopt a more gradual approach by not seeking to "eliminate" all mercury use so quickly, with the intention of using a combination of "reduction" with "elimination" plans for the most hazardous practices (The Herald, 2016). Debates about mercury in Indonesia are thus occurring in the context of significant global debate in which mercury is recognized as both a serious transboundary pollutant and a globally traded product that has a long history of being exported – controversially – from wealthy countries to poorer countries (Selin, 2011, 2014a, 2014b; Veiga and Marshall, 2016; Veiga et al., 2006).

Numerous studies have found excessive use of mercury to amalgamate the whole ore in ball mills (Ismawati, 2014) and significant releases of mercury into the air and water, documenting ecological costs and health costs from mercury exposure – in many/most cases very significantly exceeding the level declared safe by the World Health Organisation (Arifin et al., 2015). Hundreds of severely contaminated hot spots have been identified, including some of the most polluted places in the world, with Balifokus Foundation reporting that the number of ASGM hot spots in Indonesia almost doubled between 2010 and 2015 (Balifokus, 2015). Concerns have generated a vast body of research and environmental monitoring, including much detailed work on the impact of mercury in or near amalgamation tailing ponds and discharge sites (Krisnayanti et al., 2012; Palapa and Maramis, 2015) and downstream ecological cost assessment (Castilhos et al., 2006). The need for both *international mercury trade controls* and local *education-oriented approaches* to reduce mercury use in mining communities has been recognized by Indonesia's government, as reflected in preparatory documents designed to create its National Action Plan for ASGM as part of the Minamata Convention, however the *socioeconomic barriers* to mercury phase-out have generated less literature in Indonesia and less attention in the National Action Plan. Although Annex C of the Convention lists measures to educate miners and the public about mercury risks, introduce alternative technologies and regulate ASGM, treaty implementation trajectories that fail to break from extractive sector dynamics that perpetuate inequities and marginalise the most impoverished actors in the sector have to be viewed with caution (Spiegel et al., 2015; Spiegel, 2017). As with other global treaties that give "flexibility" to signatories, the Minamata Convention's requirements leave considerable space for interpretation at the country level, beckoning a rethinking of the inter-linked ecological and economic relationships that need to be understood in planning and implementation processes.

3. Methodology and Analytic Approach

Our analysis draws on field experiences of the authorship team across multiple settings, including critical insights acquired during action research in gold mining areas in South Kalimantan, Central Kalimantan, Central Java, East Java and West Java over a period of 10 years. Our methodology draws particularly on synthesizing lessons from the experiences of several of the authors with the Indonesian organisation Yayasan Tambuhak Sinta (YTS), that since the mid-2000s has participated in interventions focusing on assisting small-scale gold miners to reduce mercury use, exposure and pollution. The projects YTS implemented took place in diverse locales including remote gold mining locations in forests and degraded lands (where gold-contaminated tailings are released into the ground and streams) as well as urban gold shops in towns (where mercury from gold-mercury amalgams is released in vapour form), with United Nations agencies' support. During technology training demonstrations on-site with small-scale gold miners as well as interviews off-site, questions were asked about socioeconomic and technological challenges associated with phasing out mercury use and the perceived national planning priorities for addressing challenges. Follow-up questions – in some cases several months after the interventions finished – helped to monitor on-going challenges articulated by people involved in ASGM. Synthesis of lessons learned from research in these projects was supplemented by insights gained when some of the authors were involved in workshops with government officials to help develop the National Action Plans for ASGM and on-going interactions with officials involved with the implementation of the Minamata Convention. Our analysis was also informed by analysing documents from the UN and Indonesian government. Extensive discussions were also held with mercury traders, including traveling with a bulk mercury trader to ASGM sites.

The approach guiding our analysis draws on Martinez-Alier et al.'s (2010) discussion of social metabolism and material flows in extractive sector economies, encouraging a shift away from thinking in narrow terms about technological and social variables in order to appreciate complex and changing processes that underpin inter-linked ecological degradation and economic inequities. By "social metabolism" Martinez-Alier et al. (2010) refer to "the manner in which human societies organize their growing exchanges of energy and materials with the environment" articulating as a starting premise of analysis "the understanding that economic change generally occurs for the benefit of some groups and at the expense of other existing or future groups," and stressing the relevance of inequalities of power, land rights, resource access and income. Lamenting that many research networks on mining and other resources communicate their research "without bridges to the research on conflicts on transport and waste disposal," Martinez-Allier's work has galvanized considerable attention in the field of ecological economics on material flows, power dynamics and ecological distribution conflicts as well as modes of resistance to the extractive sector generally (Conde, 2017). Our analysis is also informed by a seminal paper published in *Ecological Economics* more than 15 years ago in which Marieke Heemskerk explored the economics of ASGM that affect the decisions of miners regarding which technology to adopt. Her study argued that technology choices and gold production practices in Suriname were often *not* influenced by official mining regulations or the market price of mercury – as is sometimes assumed – because "mercury accounted for only 1–2% of monthly production expenses" (Heemskerk, 2001, p. 300) for low-income gold miners. Documenting how restrictive governance measures to control gold miners' practices and mercury trade have often been fruitless, Heemskerk called for more comprehensive research and policy approaches that are attuned to social and economic constraints in mining communities (see also Heemskerk, 2005).

More recent studies in *Ecological Economics* have elaborated on ecological economics paradigms for understanding ASGM in Colombia –

[1] See Gamu et al. (2015) for wider review of the potential ways in which mining can contribute to poverty alleviation and/or exacerbation.

highlighting the need for considering "collective" strategies for promoting cleaner gold production and examining processes of forming cooperatives (among small-scale miners) that might facilitate technology transfer away from mercury use (Saldarriaga-Isaza et al., 2015a; Saldarriaga-Isaza et al., 2015b). Characterizing the technological choices miners in ASGM have to make as fitting the definition of a "public-good dilemma" of a common-pool socio-ecological systems resource, Saldarriaga-Isaza et al. (2013) explained that the technological decision facing miners involves a trade-off in which miners may choose mercury amalgamation - the cheapest and easiest-to-handle technique available – in order to maximize short-term individual profits, but in the long-run, the entire ASGM community, which includes these individual miners, is worse off than with the choice of a cleaner and more productive technology. Exploring how cooperative management can encourage access to cleaner and more productive technologies, the authors also noted that support from external parties "could help miners to break out of the vicious cycle in which they are trapped, due to, *inter alia*, mercury utilization" and they called for "training in the operation of new equipment, education programs, and other policies that focus on the access and switch to better practices, and campaigns to foster social capital." Citing Cardenas et al. (2002), they also pointed to experimental evidence that inequality affects decisions in public-good dilemmas and called for further research into other factors that affect choices relevant to mercury reduction. Our approach, developed in the sections below, provides scrutiny to two particular areas – new material flows of mercury due to cinnabar mining and the embedded nature of mercury use in particular power-laden socioeconomic relationships in gold mining regions – described respectively in the next two sections.

4. Implications of New Mercury Production from Cinnabar Mining

Despite the assumption - and hope - held by academics (e.g. Hylander, 2001) that global restrictions on the trade of mercury would lead to greater difficulties in accessing mercury, higher mercury prices and thus reductions in mercury use,[2] the economy of mercury use that has developed in Indonesia[3] presents a contradictory picture. We have found that in recent years mercury prices for gold miners in Indonesia have been falling significantly, not increasing, and that this is the case in large part because of recent increases in domestic cinnabar mining and mercury production. A vivid illustration of why this is came from Darma (a pseudonym), a mercury trader in Jakarta who has been trading mercury for the past 4 years, who was interviewed for this study in Jakarta and West Java. In an interview in November 2016, he explained that every week, a non-commercial airplane delivers mercury mined from Seram Island in Maluku Province to Jakarta, supplying several tonnes at a time. He explained that he usually buys and trades 3 t of mercury per week[4] and that the Maluku mercury mine has been a major source of economic change locally and a key contributor to cheap mercury supplies throughout Indonesia, from Java to Kalimantan and beyond, with most of the mercury ultimately used for small-scale gold extraction. Production at the particular cinnabar mining area described by Darma is estimated at 20 t of mercury per month, involving at least 1000 workers. More broadly, another interviewee noted that there are more than 3000[5] workers in the cinnabar mining operations in the Seram region, producing approximately 700 t of cinnabar ore - at least 50% of which is mercury - per year, bringing estimated mercury production from this region to at least 350 t per year (in recent years).

Cinnabar miners in this region are mostly former artisanal and small-scale gold miners who left gold mining after a large-scale gold mining company came to their area and pressured them to leave. Both interviewees above explained that mercury prices have decreased significantly over the past 5 years due to these new domestic mercury supplies, that powerful people (with connections to the army) have economic interests in mercury trading and that attempts by the Ministry of Environment to curtail the mercury production could therefore be met with resistance. What does the future hold for mercury mining and trading? What impacts will this have on national plans to reduce mercury use in gold mining? Small-scale miners in the region believe that mercury mining and trade is likely to continue as long as powerful actors support it (even if some government officials do not).

While these accounts of cinnabar mining give context for understanding how unlikely it is that the government's "2018" mercury phase-out target can be reached (unless very rapid actions are taken to better control the flow of mercury from cinnabar mining and shut down such operations, for example), they also illustrate how new domestic mercury production since 2012 has been reconfiguring the social metabolism that connects different parts of the extractive economy. In the region of Maluku that Darma described, the cinnabar that is extracted is estimated to be (in some cases) as high as 65% mercury, producing new economies of manufacturing in other islands in Indonesia. According to Darma in 2016, often 75% of the cinnabar from that particular area was being brought to the Jakarta-West Java area for processing (to liquid mercury) before being sent elsewhere for use in gold mining, while the other 25% was being sent to Surabaya (East Java), where it is also being processed for use for gold mining. The transport of cinnabar between Maluku and Java is often by boat but also - in some cases - by airplane. Issues of domestic mercury production and trade have barely been reported in the news media due to their covert nature and their recent emergence (just over the past five years), but televised news pieces in 2017 have explained how mercury-rich cinnabar mined in Maluku makes its way to Surabaya (by boat) and then to several processing areas in Java Island including some 60 processing furnaces in Sukabumi, in West Java, where mercury processors – like gold miners – are facing severe levels of toxic exposure.[6] A recent NGO report suggests that 30 cinnabar distilleries in Sukabumi are producing "at least 36 tons of elemental mercury per day" (Balifokus, 2017, p. 34).[7] Another interviewee in our study noted in April 2017 that regions in Maluku – specifically, Ambon City and Seram – have also seen the development of mercury processing activities between December 2016 and April 2017, indicating that there has been an increasingly diversified network of processing areas. The television piece on Sukabumi noted - as Darma (and other sources) also articulated - that for gold miners, prices of mercury have been decreasing significantly due to these new mercury supplies. Darma describes the price of unprocessed cinnabar ore as being 100,000 Rupiah per kg ($7.5 USD); whereas mercury extracted from the cinnabar stone is sold for between 250,000 Rupiah ($18.75 USD) and 500,000 Rupiah ($37.50 USD) per kg. By contrast, he reported that imported mercury from Germany, Spain[8] and other countries costs up to 1.6 million Rupiah ($120.00 USD) per kg.

Corroborating the above accounts, we collected evidence in other parts of Indonesia where, in 2016, mercury was available at significantly lower prices than several years previously. For example, in Murung Raya District in Central Kalimantan, mercury was said by local small-scale gold miners to have cost one million Rupiah per kilogram in 2007 but they were paying only half a million Rupiah ($40.00 USD) per kilogram in November 2016.

[2] As discussed by Spiegel et al. (2005), mercury prices internationally had tripled in the years prior to a European Union-led effort to curb global mercury trade in 2005.

[3] Indonesia saw a reduction of official mercury imports in recent years despite the concurrent rise in gold mining activity. However, the official tracking of mercury imports, as stressed elsewhere (Balifokus, 2015; Ismawati, 2014), often masks the actual unofficial mercury trade dynamics.

[4] At the time of the interview, Darma explained that he was about to sell 20 t of mercury.

[5] Interviewee with small-scale gold miner, April 2017.

[6] Metro TV news covered a multi-part series on this, available to view here: http://video.metrotvnews.com/metro-realitas/8koX3pWK-racun-merkuri-made-in-sukabumi-1 In this report, mercury content in cinnabar (obtained from Seram) is said to be 40–60% and furnaces in cinnabar processing sites in Parakansalak village are described as hazardous places while also providing sources of livelihood.

[7] These new mercury production dynamics are partly why "In 2016, Indonesia became one of the largest mercury producers and exporters in the world, exporting 635 tons of mercury to 13 countries" (Balifokus, 2017, p. 5).

[8] If this interviewee is correct, this mercury trade would be illegal since both Germany and Spain are in the EU which has an export ban.

Partly, they reasoned, that this is because there are more mercury dealers now (along with an increase in gold mining activity), thus raising competition, but mainly it arises due to the fact that there are now two different kinds of mercury on the market, namely internationally imported mercury and domestically mined mercury (which is believed to be of inferior quality), with the more expensive imported mercury being used to process high quality ore and the cheaper domestic mercury being used for low quality ore.

Beyond Maluku's cinnabar mining (and affiliated mercury processing in Jakarta and other cities in Java), interviewees involved in small-scale gold mining reported that there have been new mercury supplies from cinnabar mining elsewhere in Indonesia. For example, YTS staff training gold miners in East Java to phase out hazardous practices of mercury use received information that cinnabar comes from West Kalimantan and Aceh. Additionally, training staff received information that cinnabar is traded through Tulung Agung in East Java and that mercury ore is transported to Tirtomoyo district (and Purworejo) where it is processed into elemental mercury for use in ASGM. They further noted that the resulting local mercury product is sold more cheaply than imported mercury, as the quality is considered to be lower than imported mercury there as well. In several ASGM training sites selected for YTS capacity-building activities, the increased cinnabar mining was the unambiguous cause for the recent drop in the price of mercury, and experiences suggest that domestically produced "*cheap new mercury*" is connected to increased mercury use and pollution, particularly considering the widespread belief among gold miners that using excess mercury will lead to more gold recovery. Past studies note that Indonesia's ASGM operations use more mercury per gram of gold than almost any other country.[9]

At a Minamata Convention National Action Planning workshop in Jakarta in September 2015, the production of new mercury from cinnabar mined in West Kalimantan was one of the subjects addressed by government authorities.[10] NGOs expressed the concern that domestic mercury manufacturing could be taking place at considerable scale and that mercury from domestic production is being sold to gold miners in several provinces. Government officials from the Ministry of Minerals and Energy noted that no permits for cinnabar mining had been given from national mining authorities – though district government authorities are often disconnected from national authorities in how they manage mining, and some interviewees noted that regional politicians could have interests in the cinnabar production. Importantly, Indonesia *signed* the Minamata Convention in 2013 but it is not yet *ratified*; thus cinnabar mining is not yet prohibited, as the Convention only restricts "new" - not pre-existing - mining of mercury: "Each Party shall not allow primary mercury mining that was not being conducted within its territory at the date of entry into force of the Convention…" (Article 3.3), allowing already-existing mercury mining to continue "for a period of up to fifteen years" (Article 3.4). This "grand-father" clause (heavily contested by environmentalists) could result in significant ongoing mercury use from domestically mined mercury, a loophole that could yield devastating pollution costs.

In 2017, commenting on the inter-governmental negotiations that shaped the Convention, an environmental official noted "even though there is a 15-year grandfather clause, primary mined mercury *cannot* be used in ASGM immediately upon entry into force. This is an important point that these new primary miners are missing" (interviewee's emphasis in italics, interviewed, January 16, 2017). This interviewee reflected on the history of the inter-governmental negotiations around the 'grandfather clause' – noting that this clause was "largely a concession to China to support their VCM [vinyl chloride monomer] production" while also cautioning that countries with new mercury mining could have a "rude awakening" when the Convention enters into force (after being ratified) as this trade of mercury to ASGM would immediately become illegal. Indeed, Lennett and Gutierrez (2015), in their manual on ratification, likewise stressed that countries that wish to make use of Article 3.4 need to be aware that, upon ratification, "Mercury produced from existing mines cannot be used for ASGM, since ASGM is not included among the allowed uses for this mercury specified in paragraph 4 of Article 3." In Indonesia, there has been significant scepticism - and doubt - from all stakeholders (including many government officials) about whether there is sufficient capacity in national, provincial and district government agencies to implement these regulatory measures. Moreover, there has been considerable doubt that any ban on mercury mining (whether *immediate*, over a 15-year period or otherwise) would be effective if there continues to be a strong demand for mercury.

5. From "Free Mercury" to the Ecological Economics of Adopting Cleaner Technology: Engaging Socioeconomic and Power Dynamics

The recent increase in inexpensive mercury from local cinnabar mining made available to the ASGM sector in Indonesia is part of a wider story of a changing social metabolism for mercury; whereas the cinnabar production speaks to the *'supply'* side, the *'demand'* side of the story is marked by highly uneven socioeconomic processes and power dynamics within the ASGM sector itself that are driving on-going mercury demand. The data gathered at the YTS training sites showed that the price of mercury paid by small-scale miners varied considerably from site to site and situation to situation while the socioeconomic relationships of ASGM also varied considerably.

In an ASGM site in Kebonsari in East Java, mercury prices ranged from Rp 600,000 per kg ($45.00 USD) for high quality (imported mercury) to Rp 250,000 ($18.75) per kg for low quality (domestic) mercury. Most miners in Kebonsari were found to spend somewhere between Rp 197,000 to Rp 244,000 ($14.78 to $18.30 USD) on mercury per month. In one case in Central Java, others used imported mercury purchased at Rp. 800,000 ($60.00 USD) per kg (village of Paningkaban, in the district of Banyumas, Central Java). Notably, these findings are considerably different from the ASGM situation in Suriname that Heemskerk (2001) described 15 years ago – a situation where mercury prices were deemed relatively insignificant in the overall picture of production costs. In the case of Kebonsari, although small 100 g parcels of mercury could be purchased in a local village store, most miners bought their mercury several kilograms at a time, from bulk suppliers. Large differences in mercury use can often be attributed to different scales of mining and processing capacity in each village as well as differences in the nature of the processing. Also, though, when people are dealing with higher grades of gold in the ore or believe they are (in hard rock), they use more mercury.[11] The amount of mercury used, and emitted into the environment, however, is not only influenced by the

[9] According to a report released by Balifokus (2015), some studies in Indonesia show that miners used "up to 60 g of mercury per gram of gold produced" – considerably higher than what other studies have found – "5–10 g of mercury per gram gold produced" (IPEN, 2015, p. 11).

[10] It should also be noted that in the years leading up to the negotiations for the Minamata Convention on Mercury in 2013, UNEP facilitated a range of policy workshops that focused on existing mercury mining in other countries. In particular, a primary mercury mine in Kyrgyzstan that was recognized by UNEP as "the only operation which supplies primary mined mercury to the global market place." UNEP reports also discussed other countries' mercury mining – albeit not Indonesia, which was not identified as a significant mercury mining country at the time – while noting that Slovenia and Algeria had ceased operations due to economic and technical challenges, while mercury mining in Spain "experienced pressure from growing international concern regarding mercury pollution which led to closure of this, the biggest mercury mine in the world in 2004." China's mercury mining was also discussed by UNEP in global mercury policy workshops, though it was believed China's mercury largely remains within China rather than being traded internationally (UNEP, 2009). One of the authors in our study visited mercury mines in Mexico in 2017, finding that mercury production in the province of Queretaro involves 1000 miners, producing nearly 300 t per annum of Hg, which is exported to other countries in Latin America.

[11] The greater use of mercury/tromol/day seems associated with expectations of greater recovery of gold: it was estimated by miners we interviewed that 20 times the mercury = 4 times more gold.

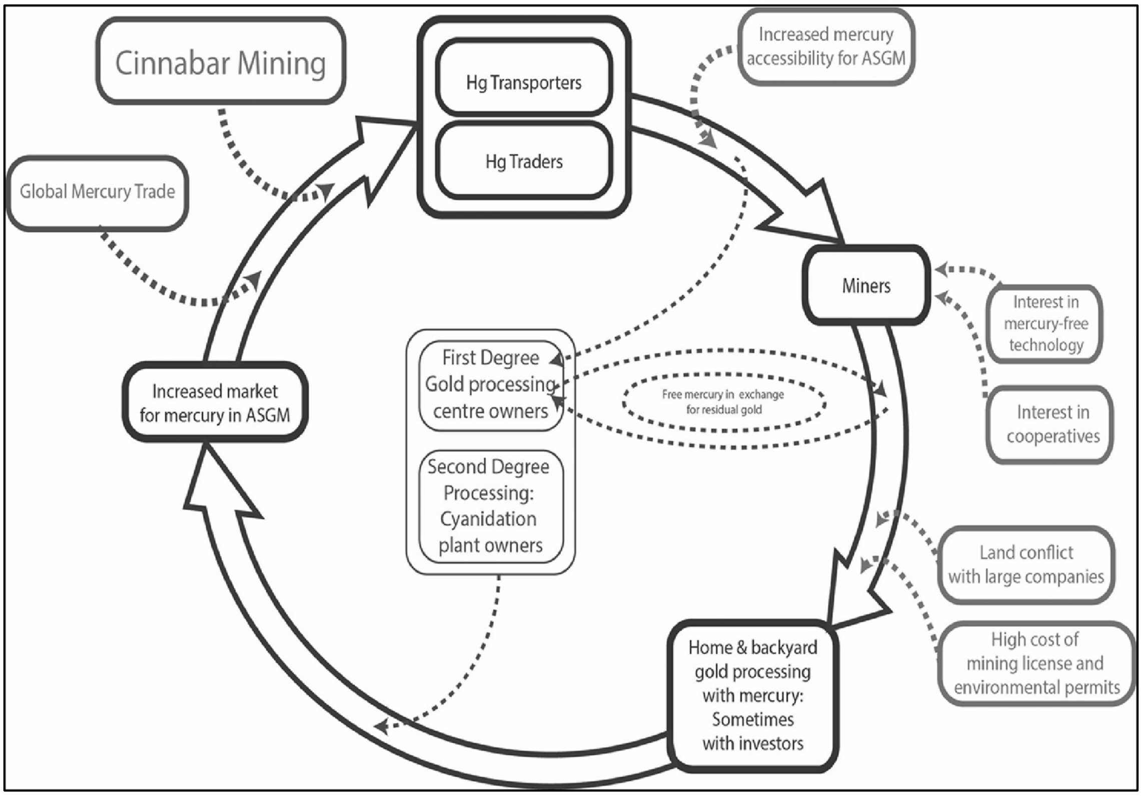

Fig. 1. Social metabolism* of mercury (Hg) supply and use in Indonesia's small-scale gold mining sector (a simplified rendering).
**Here we refer to inter-related processes, recognizing that this diagram is not comprehensive. Socioeconomic inequities that drive entry into ASGM as a livelihood are not shown in this diagram, nor are the impacts of mercury use and cyanide use, which can produce negative social, economic and ecological costs (in mining regions and downstream).* (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

scale of operation and geological factors, but also by key economic dynamics around gold processing; these economic dynamics around gold processing are, meanwhile, profoundly shaped by land use conflicts and challenges in legalising ASGM, which can hinder efforts at forming cooperatives to facilitate uptake of cleaner technologies. Also mercury suppliers/gold dealers/processors often have interests in keeping workers in small-scale mining sites using mercury precisely because it is inefficient, leaving gold in tailings and keeping them in debt to the financiers. A simplified schematic rendering of the social metabolism of mercury in ASGM in Indonesia, taking into account these inter-related parts, is depicted in Fig. 1.

As shown in Fig. 1, mercury is often used both in "home and backyard" small-scale mineral processing activities as well as in more capital-intensive processing centres, frequently in conjunction with cyanidation methods, to extract gold. Globally in the ASGM sector there are an increasing number of processing centres with cyanidation plants that purport to phase out mercury use - and break the vicious cycle that is depicted in Fig. 1 - but we found that these often in fact first use mercury to recover the easily extractable gold, and then cyanide to extract the residual gold, as other studies have also noted elsewhere (Veiga et al., 2014b; Drace et al., 2016). To replace mercury amalgamation, many international donors often promote the "scaling up" of technology solutions that seem to work in one region, sometimes seeing a combination of (often expensive) mercury-free extraction technology and microfinance loans to be the solution for artisanal miners. However, we observed that many ASGM activities in Indonesia involve poorer miners, whereas processing centres promoted by government agencies or donors are often expensive and only suitable for certain types of ore. As Sulaiman et al. (2006) noted several years ago, there has been an "incomplete transition" from mercury amalgamation to cyanidation methods in Indonesia when foreign donors funded a swift technology transfer effort in a region where miners were not prepared to stop mercury use. As noted by Veiga and colleagues, the end result of such interventions is the use of mercury and cyanide together creating an even more toxic pollution hazard (Veiga et al., 2014a, 2014b). Several of the sites we studied included situations where cyanidation and mercury were already used together as well as sites where cyanide was not used. An ecological economics approach needs to recognize that the geology, scale of operation, knowledge of risks and availability of alternate technology are intricately linked not only to the economics of mercury, but to socioeconomic and power relationships that can be entrenched or that might change over time. In the sections below we discuss particular contexts from YTS interventions seeking to phase out mercury in ASGM, illustrating some of the issues at play.

5.1. Karang Jawa: Power Dynamics in a Combined Mercury-Cyanidation Situation

In South Kalimantan, YTS training staff performed a detailed study of the processing site of Karang Jawa, in Karang Taruna village in the subdistrict of Pelaihari. At that time, the team collected baseline data from respondents working as miners and processors and built relationships with the staff at the subdistrict health clinic (Puskesmas). It was found that miners had relatively high monthly incomes (when compared with other miners in other ASGM sites), in the range of Rp. 3,000,000 to Rp. 5,000,000 ($225 to $375 USD) or more. Yet the data collected from men and women exposed to amalgam burning activities revealed that their overall level of knowledge about the dangers to their health of their exposure to mercury was low, as was their awareness of mercury-free alternative approaches to capturing gold. Risks associated with combining use of mercury and cyanidation were also not known. Having identified Karang Jawa as an important processing site, this lack of risk awareness reinforced the intention of YTS to conduct interventions at this location. However, after a careful analysis of the socio-

Fig. 2. Tromols for mercury amalgamation at homes in Jendi.
Photo source: authors.

economic relationships between the miners and processors, YTS staff realized that establishing a centre at the Karang Jawa site could be highly problematic; the main reason for this being that all of the processing sheds at this location operate on a for-hire (rental) system whereby the miners bring their own ore to the shed for processing by the shed workers at no cost. In Karang Jawa, like in many other sites across Indonesia in which YTS had conducted intervention projects, owners of gold processing centres were providing *mercury for free* to small-scale gold miners who processed their ore there – on condition that miners leave their tailing waste behind. The tailing waste then becomes the property of the processor, who uses a cyanidation process to extract the residual gold that small-scale gold miners cannot obtain by amalgamation at the first stage of gold recovery.

In this labour arrangement with free mercury supplies, little incentive exists for individual miners to reduce the utilization of large quantities of mercury inside the tromols (grinding drums).[12] As mercury is highly inefficient at gold recovery (recovering only the free gold particles), often less than 30% of the gold is extracted from the ore during this process, meaning that the remaining gold becomes the property of the processors. The introduction of a more efficient mercury-free method - to extract most of the gold during the initial processing run - would therefore be very detrimental to the business interests of the processors operating on the 'rental' system. We observed that there were also strong signs of involvement of the state's security in ASGM activities, particularly at the cyanide installations in processing centres and in the gold market. The analysis of the YTS training staff was that successful project activities might also lead to the demise of these business interests, as cyanide tank owners also reap their rewards from the reprocessing of mercury-contaminated tailings.

Without a strong welcoming environment, the team members concluded that it would be unwise to choose this location for a mercury-free demonstration centre, despite the obvious need for an intervention to prevent the high level of mercury emissions in the township. In June 2015, YTS decided to move the project to the village of Paningkaban in the district of Banyumas in Central Java, where YTS had an existing relationship with a miner's cooperative that had full control of the mining and processing of their ore. YTS conducted action-research at the site in response to a request from the District Mining Agency for technical assistance. YTS staff, working with the miner's cooperative (in Igir Salak in Paningkaban village) and one local champion from Cihonje Village, conducted three mercury-free processing runs, and produced 30 kg of concentrate, which, on careful analysis, confirmed that it was indeed possible to upgrade the concentrate sufficiently at this site to allow for smelting of the super-concentrate as an alternative to using mercury and cyanide.[13] The story here – a natural experiment - thus highlights that it is not only the question of technology choices but also the existing socio-economics and daunting power dynamics that will determine the success or failure of any mercury phase-out endeavour.

5.2. Jendi: Complexities of "Collective" Planning Amidst Land Conflict and Without Licenses

YTS research in the Wonogiri regency of Central Java brought forward a different set of dilemmas in pursuing strategies to phase out mercury. In a very detailed study of ASGM practices in the village of Jendi (Agrawal et al., 2014), YTS found 222 miners operating 741 tromols in the vicinity of their homes (Fig. 2). Miners pour mercury into the tromols and, while most miners are aware of some degree of inefficiencies and mercury losses, whole ore amalgamation remains the most common practice, simply because of the ease of operation and a lack of other ready alternatives. YTS research explored the limited choices miners felt they had for primary recovery of gold, finding that it is only when the miners are willing to give up their control over the processing of their ore that a wider range of more sophisticated technologies becomes available to them. While miners can make significant reductions in mercury use/release by using simple gravity concentration prior to amalgamation, almost all sophisticated technologies to eliminate mercury are relatively unaffordable to the average miner. Thus, if miners are to stop using mercury, they have three choices - use gravity methods to obtain their gold themselves; sell their ore (or ore concentrate) to a dealer or owner of a sophisticated facility (where it would likely be leached it with cyanide); or, as Saldarriaga-Isaza et al. (2015a, 2015b) showed was a desirable option, form a "collective" in which a group of miners could pool their resources to switch to a more expensive but environmentally friendlier mercury-free gold extraction process. As Saldarriaga-Isaza and colleagues explain, this third option can take the form of a cooperative – an idea that was, for many small-scale miners in Jendi, highly desirable. Indeed the value system displayed by miners was (contrary to popular media portrayals of miners as individualistic) welcoming to ideas of cooperative mining and collective stewardship.

We found that the average miner in this study site owns three or four tromols and operates continually at the back of the house, allowing miners to have full control over their own ore, even though this means

[12] In some small-scale gold extraction processes in Karang Jawa approximately 20 g of mercury are emitted into the environment per day per tromol to produce 1 g of gold– a dangerous practice that exceeds the amounts used and lost in many other ASGM contexts.

[13] We stress that there is no one-size-fits-all 'silver bullet' solution and that initiatives aiming to reduce or eliminate mercury need to be carefully informed by local labour dynamics and local geology (among other factors). In various sites where gold is very fine, past assessments suggest that without mercury or cyanide, gold recovery could be very low, as was tested in the UNIDO/GEF/UNDP Global Mercury Project in Talawaan. Globally, some technical training projects encourage the idea of selling ores to cyanidation companies rather than processing (using gravity or other processing methods) (see Veiga et al., 2015).

that to extract full value from their ore requires additional processing, the cheapest and easiest being using mercury. Small-scale miners were asked by the research team what it would take to transition from mercury-using backyard processing to collective mercury-free processing. In such a scenario, the ore or concentrate would be purchased from the miners (at prices that would have to be collectively determined in a trusting relationship), then milled and processed on-site to recover most of the gold content using mercury-free alternatives. Such a collective processing facility could operate at the community-scale or at the commercial-scale; whereas a company-run facility might have the capacity to process 10 t of ore per day, a community-run facility would have a one-tonne capacity at most but would provide the community with a model as to how to end the problem of mercury use and waste dumping.[14] Indicative costs for establishing such a facility were subsequently discussed with donors and government officials by YTS staff following discussions with community stakeholders in the Jendi small-scale mining site; estimated costs based on a projected 0.2 t of gold production/per day facility were 1176 million Rupiah ($88,328 USD), and 6360 million Rupiah ($477,692 USD), for a larger facility with 1 t gold production/day. In presenting the potential benefits to the government, YTS staff also explained that, among the various other potential benefits for miners, if miners were to sell their rock (to a processing centre) rather than run their tromols, they could reduce their household expenses for electricity and water by an average of 300,000 Rupiah per month ($22.51 USD). Moreover, they would no longer need to purchase any mercury - a cost often of another 300,000 Rupiah per month – spent just on mercury. Taken together, these costs can be significant portions of revenues generated from backyard gold production. Yet, major challenges encountered in the fieldwork - that stymied the implementation of the desired approach - centred on significant power interests; in addition to the vested interests in keeping the existing processing centres operating and exploiting the small-scale miners in an “informal” (i.e. non-legalised) arrangement, land use conflict with a company in the area (over the rights to mine) made future planning difficult for the mining community. The artisanal and small-scale miners did not have formal licenses, despite having attempted to acquire licenses. Although Danish donors were prepared to support significant funding to conduct technology interventions and to support cooperative structures, the government decided not to designate the area for a “Community Mining Zone” (WPR – Wilayah Pertambangan Rakyat) and instead give the license to a private company.

This decision in the Jendi village context is reflective of a much wider problem of resource rights allocation that undermines sound environmental management in Java as well as nationally. Central government mining authorities have reported that only approximately 90 zones have been designated for “community mining” across the country – although government licenses to mine have been issued in only a small fraction of these.[15] Operating widely in contexts with insecure land claims presents challenges for local environmental/livelihood planning, as the experience in Jendi illustrated – pollution risk reduction campaigns can be significantly limited by the extensive lack of resource rights. While declaring their commitment to be free from mercury by 2018, the National Indonesian Association of Community Miners has argued that responsible community mining would only be possible once legal issues are resolved. Small-scale gold miners in Jendi have repeatedly made efforts to make their activities legal – through advocacies to the district as well as provincial and national government authorities (and through requests made to YTS for help with facilitating dialogue with the government) – but to date these efforts have not been met with new small-scale mining legalisation opportunities. Small-scale gold miners in the study area have also voiced frustration with mercury risk-“awareness” efforts in Jendi, where government mercury programmes have narrowly focused on health impacts of mercury, warning against using mercury for gold processing without offering feasible alternatives.

5.3. Synthesizing the Importance of Addressing the Socioeconomics and Power Relations

Although campaigns to raise awareness of ecological and health risks in ASGM sites can be important, we found that unless closely linked to addressing socioeconomic barriers to technology transfer and concrete efforts to minimise mercury use, such campaigns can have the effect of *stigmatizing* miners without reducing mercury use and pollution. To give one example of this, some miners in Jendi expressed annoyance after a government-led health awareness event that offered no feasible alternatives to mercury use. Our findings also support the view that narrow emphasis on contamination can also have the effect of exacerbating social tensions *between* miners and others in society – a point made by Tschakert and Singha (2007) in addressing mercury pollution debates in Ghana's ASGM sector, where discourses of contamination have contributed to the “criminalization” discourses that marginalise miners. Furthermore, issues of governance coordination across ministries and implementation agencies are nested in political complexities that require careful attention. In a past issue of *Ecological Economics*, Gallemore et al. (2015) discussed governance and transaction costs in Indonesia associated with REDD + (Reducing Emissions from Deforestation and Forest Degradation), explaining how coordination across governmental levels has been weak and how local organisations' efforts to get access to different agencies are subject to power imbalances. Experience of YTS in the context of planning for Minamata Convention implementation highlighted that many government authorities must be involved at national, regional and district levels. Notably, the fieldwork in 2016 occurred in a transition period in which government powers over licensing for mining were being shifted from district to provincial government levels, generating much confusion and concerns that achieving ‘legal’ status was becoming more difficult.

In North Sulawesi, East Indonesia, Langston et al. (2015) noted that small-scale gold mining contributes more to the local economy than large-scale mining and that local impacts of large-scale mining are more controversial in communities. They also document a case study where mercury phase-out was possible. Nonetheless, while large-scale mining operations have long ago phased out mercury use and while ASGM operations in Indonesia have *in some cases* been able to do so, the transition to mercury-free methods (including cyanidation) still often requires more economic capital and training that most artisanal miners can access – and requires a significant re-organisation of miners' labour structure, involving different systems of payment and revenue sharing. The Karang Jawa situation illustrated a labour relation set-up whereby processing centre owners make their profit from the inefficiency of mercury technology so much so that they are prepared to provide mercury free of charge to de-incentivize any efforts to seek alternatives. The lack of knowledge of the hazards of mercury to health and environment, let alone the existence of alternatives was stark, yet could not be addressed by the intervention proposed by YTS because of the financial arrangement between the miners and the owners of the capital equipment needed to process the ore. The situation was particularly difficult as it was not only the business interests of the owners of the

[14] We found that most of the low-value tailings were being dumped into local waterways, whereas the higher-value tailings were being sold to regional buyers, thus spreading the contamination problem widely throughout Java.

[15] During one of the Minamata Convention National Action Plan workshops in September 2015, the Ministry of Environment and Forestry presented a database on open access lands gathered during the period 2010 to 2014, involving 302 ASM locations in 29 provinces (DKI Jakarta and Central Kalimantan were not included). An inventory was performed that covered four aspects: (1) environmental damage, (2) ongoing and past conflicts, (3) the wellbeing of community miners, including women and children (4) the commitment of local government. The presentation noted that there are 92 districts (Kabupaten) with WPR areas, but only 9 have been legally formalized. ASM locations are dominated by gold mining, of which 202 are informal ASGM and only 44 locations have some form of mining permit (IUP/IPR).

primary processing step that stood in the way, but the capital for secondary processing – using cyanidation rested in the hands of powerful actors. Efforts to phase out mercury in this situation would be daunting. In contrast, in Paningkaban, the existence of cooperatives allowed the promotion of mercury free technology to gain traction, supporting the arguments by Saldarriaga-Isaza et al. (2015a, 2015b) on the importance of cooperatives, even if other power interests came into play as barriers.

Technological transfer complexities also can be understood as enveloped within wider debate about how projects seeking to reduce pollution are implemented (e.g. examined in other countries by Hilson and McQuilken (2014) and Jønsson et al. (2013)), whether capacity-building to address mercury can take place where artisanal miners compete with large companies for land access (examined in other country contexts by Spiegel, 2016). The Jendi study illustrated that despite considerable interest in forming cooperatives and raising the capital needed for mercury-free processing, the inability to obtain licenses to mine created an enduring barrier. Ultimately, there are many different economic forecasts on what exactly is required to "phase out" mercury. Veiga et al. (2014b) noted that a capital influx of about US$ 10,000 per tonne of ore being processed per day is needed to establish a cleaner and profitable processing facility. As small-scale miners are not all "capitalists-in-waiting," the capital needed for a complete mercury phase-out is – in the view of many small-scale miners – well out of reach of individuals, leaving informal 'backyard' mercury processing to flourish. While costs associated with forming cooperative businesses are not insignificant (we encountered cases, such as in West Java, where small-scale miners had banded together to form cooperatives prior to advocating for small-scale mining licenses), the costs and bureaucratic complexities associated with acquiring licenses and meeting regulatory requirements (including environmental permits) are considerably greater, and sometimes require paying the equivalent of thousands of US dollars and waiting for many months. Fig. 1's depiction of the "social metabolism" of mercury along the commodity chain thus recognizes that such regulatory costs are essential to address, along with relations of production, and perhaps most importantly – at least from the perspective of small-scale mining associations - is the dispossession and land use policies that prevent the legalisation and regulation of ASGM activities. These concerns underline the need to engage miners in participatory planning that includes respecting their rights to mine – safely and in an ecologically sound manner, if the goal of phasing out mercury is to realized.

6. Concluding Remarks

Literature in the field of ecological economics has tended to discuss the gold mining sector by focusing on friction between large-scale gold mining companies and affected communities (Urkidi and Walter, 2011; Anguelovski and Alier, 2014; Avcı et al., 2010). When engaging the ASGM sector, also the source of considerable environmental concern, a vastly different sort of approach is required. While the full cost of health and ecological damage associated with mercury mining and gold mining cannot be ignored, government policymakers, like the news media, have had a tendency to promote ecological cost assessments and awareness raising (of miners and the public) about toxic risks, as the main strategy to address mercury's mounting ecological costs. However, unless policymakers and researchers adopt a more comprehensive ecological economics approach that recognizes and addresses the complex social metabolism involved in the ASGM-mercury story, such efforts to phase out mercury are unlikely to achieve significant results.

First and foremost, we conclude there is a need for researchers and policymakers to come together to discuss the economic and ecological dynamics of cinnabar (mercury) mining, including links between domestic mercury production, mercury pricing, and on-going mercury use practices, as well as potential plans for closing down mercury mines – *and providing alternative livelihoods*. Because past 'hopes' about restricting international mercury trade (i.e. that this would lead to increased mercury prices and reduced mercury use) have not been realized, new approaches for curtailing and reversing Indonesia's recent increases in mercury production should be made policy priorities. As Indonesian policymakers and researchers contemplate how to respond to the recent development of at least hundreds of tonnes of domestic mercury production per year, other case studies around the world offer useful points of comparison. For example, the Indonesian case study described here resonates with what Camacho et al. (2016) found in Mexico where "informal mercury mining" increased ten fold between 2014 and 2016, with mercury exported to ASGM locations across Latin America. Camacho and colleagues called for state support for alternative livelihoods to mercury mining, to support communities for whom employment prospects are critically limited. In Maluku, the mercury mining area we discussed in this study, many of the approximately 3000 mercury miners were formerly small-scale gold miners – before they were forced out of gold mining. This case thus underlines the importance of understanding not only technology and trade issues but also complex regional labour dynamics, which are vital to engage when planning a phase-out of mercury production. As noted by others elsewhere (Spiegel, 2009; Spiegel, 2015; Hilson, 2006) as well as by Suhartini and Abubakar (2017) in Indonesia, treating small-scale gold mining as "illegal" can have counterproductive ecological consequences. Our study has emphasized the importance of appreciating the interconnectedness of trade, labour dynamics and environmental implications when assessing the ecological economics of mercury and gold mining. A chief implication of understanding this *interconnectedness* is that researchers need to advocate for *inter-sectoral* approaches working with policymakers and diverse population groups including those involved in key extractive labour practices, creating carefully informed understandings of what a viable "socioecological transition" (see Fischer-Kowalski, and Haberl, H. (Eds.)., 2007) may mean in practice. This entails making efforts to "try to distinguish possible from impossible futures" (Martinez-Alier, 2009, p. 64) by recognizing diverse knowledge that people in mining areas can bring forward.

Secondly, we have also highlighted how mercury use practices are uneven and driven by complex *multi-scalar power relations*, such that academics need to resist attempts at 'simplifying' the social metabolism of the extractive sector with overgeneralized and abstract ideas about small-scale (and artisanal) gold miners' economic capacities. We have shown that the assumption that education and training programmes are the keys to implementing technology changes risks neglecting powerful interests at play that mitigate against changing the status quo in gold extraction techniques, at the local level of processing plants and at regional and national levels in terms of access to land and licenses. Our findings reinforce the call by Saldarriaga-Isaza et al., 2015a for supporting local cooperatives and collective solutions by small-scale gold miners, including external policy measures designed to address equity issues. Long-term community-based approaches, based on sustained trust-building relationships, are needed to engage those who are already seen as 'influential' in the communities (including owners of equipment, traders and land owners) as well as those who might not (yet) be seen locally as having the same kind of power. In the case of gold mining in Wonogiri, small-scale miners groups continued to make further requests for support several months after the intervention we examined – from donors and government officials - in efforts to acquire mining licenses and reduce mercury use. Locally engaged ecological economics research that takes into account the *longue durée* of equity struggles is crucial.

Finally, before the signing of the Minamata Convention, Andresen et al. (2013) discussed some of the perspectives of treaty negotiators who felt there was a need to leverage "more predictable funding" (p. 437) for treaty implementation. In 2014, the Global Environment Facility (GEF) announced that the GEF6 replenishment set aside $141 million for actions to implement the Minamata Convention, an amount that includes ASGM-related assessment and intervention activities, among other sectors. Indonesia's government is one of many worldwide that have received funds for assistance from the GEF since then. Government authorities are faced with the task of deciding priorities out of the dozens of activities outlined in the Minamata Convention - ranging from measuring mercury exposure levels to diagnosing health and ecosystem impacts, to designing disposal strategies, reviewing mining policies and providing training on mercury-free and mercury-reducing technologies. Different stakeholders, not surprisingly, have competing views regarding which of the above are the more urgent funding priorities. Our study leads to the conclusion that, along with *funding community initiatives*, the complex political and economic incentives, including the role of powerful interests involved with the security apparatus of the state, that drive mercury trade and mercury use, must be addressed if the trust needed to protect the environment as a public good is to be restored. Going well beyond narrow technological solutions, an ecological economics approach that addresses power relationships and dilemmas of collective planning - closely engaging changing realities and equity concerns within dynamic extractive sectors - is needed to drive the phasing out of mercury.

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